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Dare,
M. R.

Deriving Environmental Variables for and Analysis of Bull Trout Migration Project Completion Report

Final Report

Deriving Environmental Variables for and Analysis of Bull Trout Migration

Project Completion Report

Research Joint Venture Agreement 04-JV-11222014-239

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Introduction

Animal migration is a process by which populations move among connected habitats over a predictable time period (Endler 1977, cited in Hendry et al. 2004). Stream fishes typically migrate between spawning locations and downstream habitats containing adequate food resources. For migrating fish populations these habitats are typically distinct and may be separated by long distances (Northcote 1978; Northcote 1997). Migratory behavior is believed to involve increased risk of mortality as an individual moves across the landscape (Hendry et al. 2004). For successful migrants this risk, however, is annulled by increased food availability and resulting increased growth and fecundity (Gross 1987; Northcote 1992; Hendry et al. 2004). While the impetus for migration is understood, the choices made by a migrating individual to bypass or occupy certain habitats is not. This is particularly true for the migration away from spawning areas where there most likely is not a discrete endpoint recognizable by the migrating individual. The mystery regarding habitat use during and after a migration away from spawning grounds probably stems from the fact that migratory individuals have to weigh a variety of factors when selecting a particular location (Chapman 1966; Chapman and Bjornn 1969). Undoubtedly, these include site-scale features related to habitat, food availability, and predation risk (Hughes 1992; Gowan and Fausch 2002; Railsback and Harvey 2002). However, the location of the position within the stream network (e.g., the distance between a wintering location and spawning habitat) may also be important.

Bull trout *Salvelinus confluentus* are a migratory char that have been intensively studied since they received protection as a threatened species under the U.S. Endangered Species Act (USFWS 1998). Most research has focused on identifying the movement patterns of migratory individuals during upstream spawning migrations in the fall (Dare, unpublished data). Target populations have been classified as "fluvial" or "adfluvial" based on the type of post-spawn habitat used: stream fishes that migrate between headwater spawning areas and large, downstream rivers have been called fluvial populations; whereas migratory individuals moving between spawning streams and a lake or reservoir are called adfluvial (Varley and Gresswell 1988; Rieman and McIntyre 1993). Within the published literature, studies of bull trout distribution within a watershed have focused on movement patterns and timing (Fraley and Shepard 1989; Swanberg 1997; Muhlfeld et al. 2003; Muhlfeld and Marotz 2005) and more recently on linkages between life history and movement (Bahr and Shrimpton 2004; Downs et al. 2006).

While the rationale for focusing on the spawning migration and associated habitat use patterns is logical based on the management objectives for the species, the question of why a bull trout selects one location over another following spawning remains unanswered. My objective was to determine if there were identifiable environmental correlates to the distribution of migratory bull trout in the habitats they used following their migration downstream from spawning areas in the fall. In hypothesizing about the post-spawn distribution of migratory bull trout in the upper Boise River Basin I assumed that the microhabitat selection by individual bull trout would be closely tied to energy acquisition (Fausch 1984; Hughes and Dill 1990; Railsback and Harvey 2002). The distribution of the migratory population; however, would be correlated to larger-scale features of the landscape. Such landscape-scale features include distance of a particular location from spawning areas and the reservoir. This idea stems from the work by

Gowan and Fausch (2002) who studied feeding position choice by large brook trout *Salvelinus confluentus* in Colorado streams. In that study individuals that were displaced from a preferred position in a pool tended move to a secondary feeding location out of the home pool. The authors concluded that these large individuals monitored habitat conditions at a larger spatial scale than they typically occupied within a season and were able to move from their home pool to known alternative feeding areas. My hypothesis is that as the scale of movement increases so too does the scale at which an individual monitors habitat conditions around it. Therefore, within the context of seasonal migration and habitat use, landscape-scale parameters will be important factors in individual position choice. I used logistic regression analysis to determine the probability of bull trout occupancy of a stream segment based on three parameters: road presence, segment distance from Arrowrock Reservoir, and connectivity to spawning areas. I predicted bull trout occupancy would be negatively correlated with roads and positively correlated with decreasing distance from Arrowrock Reservoir and increasing connectivity to spawning areas.

Methods

Bull trout location data

I used location data collected by the U.S. Bureau of Reclamation during a multi-year study of bull trout movement and distribution associated with the repair of Arrowrock Dam (see Salow and Hostettler 2004 for a summary). The response variable used in this project was based on location data for 50 adult bull trout surgically implanted with radio transmitters during their post-spawn, downstream migration (Table 1). A detailed description of the collection and tagging methodology can be found in Salow and Hostettler (2004). I used location data based on aerial and ground-based observations from 27 September 2002 to 30 April 2003. I only included individuals for which there were at least 10 observations, which meant an individual was tracked for approximately two months.

Watershed delineation

The upper Boise River basin encompasses an area of approximately 5,700 km^2 and contains three major subbasins: the North Fork, Middle Fork, and South Fork (Figure 1). Detailed descriptions of the basin can be found in Rieman and McIntyre (1995) and Salow and Hostettler (2004). For this analysis I considered the portion of the basin upstream from Arrowrock Dam, including the South Fork of the Boise River upstream to Anderson Ranch Dam. Stream segments were identified and attributed using U.S. Geological Survey 30 m Digital Elevation Models (DEM) obtained through the TauDEM (Terrain Analysis Using Digital Elevation Models) database (Tarboton 1997). Within a TauDEM data layer a stream network is divided into segments based on tributary junctions. For this analysis I only considered stream segments downstream from potential spawning areas (patches) and therefore, I truncated the full stream network based on elevation and contributing area. Rieman and McIntyre (1995) found that bull trout presence in the Boise River basin was most common at elevations greater than 1,600 m; therefore, I removed stream segments at elevations less than 1,600 m from consideration. Streams having widths less than 2 m have a low probability of bull trout presence (Rieman and MacIntyre 1995) and Dunham and Rieman (1999) reported that

most streams in the Boise basin with contributing areas less than 400 ha were too small to support bull trout. Upon review of a map of the watershed truncated based on contributing areas less than 500 ha I opted for a more liberal contributing area criterion of 250 ha which retained several tributary streams necessary for segment delineation. The truncation procedure resulted in a stream network containing 304 stream segments (Figure 2; Table 2).

Initial inspection of the distribution of bull trout presence in the network revealed that bull trout locations were restricted to the mainstem sections of the Middle Fork, North Fork, and South Fork subbasins, and Arrowrock Reservoir (Figure 3). This resulted in a substantial skewing of the response variable: bull trout were not observed in the 230 tributary stream segments. Therefore, I used the stream segments that were classified as mainstem segments for further consideration (Table 2). This resulted in a dataset including 74 stream segments with 39 occupied segments and 35 unoccupied segments.

Environmental variable derivation

For each of the original 304 stream segments I derived a number of site-scale and watershed-scale variables (Table 3) in order to compare these attributes to bull trout presence and frequency. The site-scale variables included segment length, segment slope, segment elevation, and road presence. Segment length, calculated as the stream distance (km) between tributary confluences, was included in the TauDEM database file. For analytical purposes, this variable was treated as a nuisance variable designed to account for the idea that the probability of presence in a segment may be related to segment size. The elevation of a stream segment was calculated by averaging the upstream and downstream elevations (m) of the stream segment. These data were available in the TauDEM data file. The presence of a road within 100 m of a stream segment was determined by overlaying a shapefile that included roads onto the TauDEM layer and creating a 100-m buffer around the target stream segment. Segments were coded 1 if a road was present within 100 m and 0 if a road was absent. In order to account for first-order autocorrelation in the response variable, I developed a categorical variable to account for the possibility that a fish present in an adjacent segment would increase the probability of a fish being present in a target segment. If a fish was present in segment directly upstream, downstream, or in both segments adjacent to a target segment the segment was coded 1. If no fish was present in either of the adjacent segments, the segment was coded 0.

Watershed-scale variables included contributing area, distance to Arrowrock Reservoir, and connectivity to spawning habitat. Contributing area was calculated as the area (ha) upstream of a segment that drained into that segment. Contributing area and segment slope (%) were available in the TauDEM data file. The distance to Arrowrock Reservoir was calculated by measuring the distance (km) between the midpoint of a segment and Arrowrock Reservoir. Connectivity to spawning habitat was estimated by calculating a weighted average distance between each stream segment and 13 spawning patches in the upper Boise River basin (Figure 4). I used spawning patches identified by Rieman and McIntyre (1995) and only included those spawning patches where bull trout presence had been confirmed. Connectivity was calculated based on the following formula:

$$Connectivity_i = \sum_{1}^{13} \frac{A_j}{d_j}$$

where the connectivity (km) for segment i is equal to the area (km^2) of spawning patch j divided by the distance (km) to spawning patch j, summed for all 13 spawning patches.

Because bull trout were occupying these stream segments in the fall, winter, and spring of the year, I did not consider a temperature variable in this analysis. While temperature has been shown to be an exceedingly important variable in bull trout habitat use at other times of the year (Fraley and Shepard 1989; Rieman and McIntyre 1993), an inspection of the stream temperatures at this time of year revealed they were well within the acceptable range for bull trout occupancy.

Data analysis

Bull trout occupancy was a dichotomous variable where a segment received a score of 1 if a bull trout resided within it for two consecutive weeks. A segment received a score of 0 if it did not meet this criterion. The relationship between bull trout occupancy and environmental variables was analyzed with binary logistic regression.

In developing a logistic regression model to explain bull trout distribution within the stream network I employed the information-theoretic approach for model selection described by Burnham and Anderson (2002). I developed a global model and a series of nested candidate models that included various combinations of the variables described above (Table 4). Two variables, SEGLENGTH and FISH, were included in all the models in order to account for the correlations between segment size and fish presence and fish presence in adjacent segments and fish presence in a target segment.

I evaluated potential correlations among predictor variables by constructing a correlation matrix and calculating variance inflation factors for each predictor variable (Phillipi 1994). Several of the potential predictors were correlated with one another and I removed variables from further consideration based on the strength of their relationship to the response variable and the ecological interpretation of the relationship. For example, I selected distance to Arrowrock Reservoir over segment elevation and segment slope because of the ecological interpretability of the former variable. The variance inflation factors for the remaining variables had values less than 10.0 and did not suggest problems with multicollinearity. I evaluated the fit of the global model using the overdispersion statistic and a goodness-of-fit test (Allison 1999; Hosmer and Lemeshow 2000).

I used Akaike's Information Criterion (AIC) and AIC weights to evaluate the plausibility of the global model and candidate models (Burnham and Anderson 2002). This approach allows the modeler to objectively evaluate the relative plausibility of a suite of candidate models. I used the 1/8th rule to evaluate the relative plausibility of the candidate models (Burnham and Anderson 2002). By this rule, models having AIC weights less than 1/8th of the maximum weight were not considered plausible. The converse was also considered true: all models whose weights were within the 1/8th cutoff were considered plausible. In cases where more than one model appears plausible, the modeler is able to average the parameter estimates to develop a composite model. I averaged parameter estimates for all plausible models. For logistic regression models these parameters include odds ratios and corresponding confidence intervals. A detailed description of the information-theoretic approach, AIC, and model averaging can be

found in Burnham and Anderson (2002). Concise descriptions of the approach and specific applications are also available (Anderson et al. 2000; Thompson and Lee 2002; Hobbs and Hilborn 2006).

I evaluated the predictive power of each model by examining the proportion of concordant pairs, where a concordant pair resulted from agreement between the predicted and observed occupancy status of a stream segment. I also estimated the specificity and sensitivity of regression models (Olden and Jackson 2002). Model specificity, the ability to predict species absence, was calculated by dividing the number of segments where bull trout were predicted to be absent into the number of segments where bull trout were not observed. Model sensitivity, the ability to predict species presence, was calculated in a manner similar to specificity, except that the number of predicted and observed presences was used. In both cases, the predicted value for a segment was based on the probability of species presence calculated by a specific regression model. The cutoff for predicted occupancy status was 0.5.

Results

The best-approximating model for bull trout presence included ARROWDIST along with SEGLENGTH and FISH (Table 5). Inspection of the AIC weights revealed that all of the candidate models were plausible and parameter estimates and odds ratios for the parameters were averaged across the models (Table 6). With the exception of FISH, all of the estimated odds ratios overlapped 1.0; therefore, it is difficult to interpret the magnitude of their respective effects. An inspection of the nature of the relationship (i.e. positive or negative) between bull trout presence and the predictor variables in the composite model revealed some interesting results. Bull trout presence was negatively correlated with the presence of roads and increasing distance from Arrowrock Reservoir. However, bull trout presence was also negatively correlated, albeit weakly, with increasing connectivity.

The inclusion of segment length (SEGLENGTH) and the indicator variable for occupancy of an adjacent segment (FISH) in all models was necessary to control for the correlations between segment length and probability of occupancy and first-order autocorrelation in segment occupancy. The odds ratio for segment length supported my prediction that the probability of occupancy increased as segment length increased. This relationship, however, was not statistically significant (Table 6). Occupancy status of a segment was strongly correlated to the presence of an occupying fish in an adjacent segment and this was the only statistically significant relationship within all models. These results suggest that bull trout were patchily distributed within the stream network (Figure 3).

All of the models had high predictive power and correctly classified the status of a segment for at least 86% of the segments (Table 5). The specificity of the models ranged from 54.3 to 68.6% and the sensitivity ranged from 74.3 to 87.2% (Table 5). Model 5, the model with the highest AIC weight did not have the highest predictive power based on any of the three measurements.

Bivariate plots were useful in understanding the relationships among the predictor variables and the presence of bull trout. Bull trout occupied stream segments with contributing areas greater than 80,000 ha (Figure 5). There was not a strong demarcation between occupied and unoccupied segments with respect to segment length; however, the

majority of occupied segments were less than 5 km in length (Figure 6). A strong pattern was observed with connectivity and distance to the reservoir, where bull trout occupied only segments having connectivity less than 20 km and within 58 km of Arrowrock Reservoir (Figure 6).

Discussion

With the exception of connectivity, the nature of the relationships between bull trout occupancy and the environmental variables conformed to my predictions. The least connected segments were those that were furthest from the spawning patches located in the North Fork and Middle Fork drainages. Therefore, connectivity was lowest in the most upstream South Fork stream segments. I expected that connectivity to spawning areas would be important as all of the bull trout monitored in 2002-2003 spawned in the North Fork and Middle Fork drainages (Salow and Hostettler 2004). There are at least two possible explanations for this result. First, the odds ratio for connectivity was -0.94 and 95% confidence interval for this estimate overlapped 1.0. Therefore, it is very difficult to say whether the actual relationship between bull trout occupancy and connectivity to spawning patches is accurately estimated by the value -0.94. In other words, this result could be a statistical artifact and not a biologically meaningful description of the relationship between these two variables. The second possible explanation is ecological: large, migratory bull trout are not limited by the maximum distances they travel between spawning locations and overwintering areas in this basin. The distance between the most upstream spawning patch and the base of Anderson Ranch Dam is approximately 155 km and bull trout are believed to have previously migrated between the Snake River and spawning locations in the Boise basin, a distance of at least 200 km. Bull trout have routinely been observed to move greater than 150 km during seasonal migrations (Fraley and Shepard 1989; Swanberg 1997; Muhlfeld and Marotz 2005; Bahr and Shrimpton 2004) and Baxter (2002) observed migratory bull trout to move approximately 280 km between the Wenaha and Snake Rivers in Oregon. It is not likely, therefore, that the distance between spawning tributaries and downstream habitats in the Boise basin is a limitation to migrants.

The relationship between bull trout occupancy and connectivity may have also been confounded by the frequency of use of the South Fork of the Boise River. The South Fork was occupied by a large percentage of the migratory bull trout included in this study. The South Fork is a regulated system that supports large numbers of salmonids and is managed as a trophy fishery. Bull trout most likely migrate into this system because of habitat characteristics and abundant food supply. The South Fork, however, is the least connected of the three sub-basins. This is evident in Figure 6, which bears a distinct similarity to a map of the study area (Figure 2). The pattern in Figure 6 shows the stream segments within the South Fork are less connected to spawning areas as the distance from Arrowrock Reservoir increases. This is not the same pattern for the segments in the other two subbasins where increasing distance from the reservoir reflects movement upstream within the watershed and closer to spawning patches. Unfortunately I do not know whether historical use of the South Fork by bull trout was as extensive as it is under regulated conditions. However, it appears that the frequency of use of the South Fork exerted a substantial influence on the connectivity variable and the relationship

between bull trout occupancy and connectivity to spawning patches bears further exploration (see Future Research below).

I found bull trout occupancy was negatively correlated with the presence of roads. Similar conclusions were reached during previous studies of bull trout distribution (Rieman and McIntyre 1995; Baxter et al. 1999). There are at least two mechanisms by which a nearby road can negatively affect migratory bull trout. First, road crossings can lead to habitat degradation via increased sedimentation. Fine sediments are negatively correlated with the presence of a variety of salmonid species; however, this relationship generally factors into spawning habitat. Given the stream size of the target segments and the time of year in which they were occupied, the second potential mechanism is potentially more plausible: the presence of roads facilitates angler access. There is substantial angling pressure in the Boise basin, particularly in the South Fork. Bull trout are frequently captured by anglers throughout the watershed and illegal harvest of bull trout has been documented (Salow and Hostettler 2004).

My results suggest that segment occupancy is affected by a segment's spatial relationship with Arrowrock Reservoir. Despite the frequency of use of the South Fork, the migratory component of the population in the Boise basin is classified as adfluvial and I expected to detect a statistical signature reflecting the frequency of use of the reservoir. Stiefel and Dare (2006) monitored the movement patterns of bull trout within the reservoir in 2004-2005. The majority of bull trout in their sample occupied locations in the upstream section of the reservoir for approximately 80 % of the fall and winter of 2004-2005 (Stiefel and Dare 2006). These observations included individuals that were suspected to have moved into the South Fork for as long as two months. Previous research has found that bull trout frequently move between the reservoir and the South Fork during the winter (Salow and Hostettler 2004). Bull trout are presumably migrating to Arrowrock Reservoir in search of food; however, the frequency of segment occupancy in the South Fork suggests that food availability is sufficient to support large, migratory bull trout for extended periods. Therefore, movements between the reservoir and South Fork could be a reflection of a mobile predator searching for food. A second explanation for frequent movement between the reservoir and the South Fork is that bull trout monitor the environmental conditions related to spring migration by returning to the reservoir throughout the winter (Stiefel and Dare 2006). Spring migrations from Arrowrock Reservoir are asynchronous and bull trout begin upstream movement as early as February (Salow and Hostettler 2004). Previous research, however, has failed to identify environmental correlates to departure timing (Salow and Hostettler 2004; Stiefel and Dare 2006). Regardless of the mechanism behind the pattern, previous research supports my conclusion that the post-spawn distribution of bull trout in the Boise basin is closely tied to Arrowrock Reservoir.

Despite that fact logistic regression modeling did not result in a single best model of bull trout occupancy, my results suggest that a segment's position within the stream network affected the probability that a bull trout would be present. The plausibility of a suite of candidate models can be evaluated with AIC values and their corresponding weights. The two models with the highest AIC weights included distance to reservoir and connectivity to spawning habitat. The weights of these two models were almost double that of the next most plausible models (Table 5). There is no completely objective criterion by which a modeler can exclude one or more candidate models from

consideration (Burnham and Anderson 2002); however, I am confident in an ecological link between bull trout occupancy and a segment's spatial relationship to Arrowrock Reservoir. It is important to point out that the weight value for the model that considered distance to reservoir alone was almost twice that of the model that considered connectivity to spawning patches. These results are most certainly context dependent; i.e., other factors may be more important in other, particularly larger watersheds. At the same time, the importance of landscape-scale variables that I measured lend credence to Thompson's (1959) suggestion that habitat for a mobile salmonid should not be measured instantaneously: an individual's position at any one time is a single observation within a network bounded by the spatial extent of an individual's movements over their lifespan. While my results are certainly not unequivocal, I believe my hypothesis that the scale of environmental parameters that factor into decisions about which habitats to occupy is commensurate with the scale of habitat use measured, is supported by this research. Therefore, I believe the conclusions of Gowan and Fausch (2002) regarding the scale at which individuals monitor the habitat around them can be extended and applied to the post-spawn distribution of bull trout in the Boise basin.

Future research

My major conclusion is that it appears bull trout segment occupancy is affected by the position of a segment within a stream network. In the Boise River, the pattern of segment occupancy I observed seemed to be related to a stream segment's position relative to Arrowrock Reservoir, and to a lesser extent a segment's position relative to upstream spawning habitat. I am not suggesting that site-scale factors, particularly food availability, do not affect the decision of an individual to occupy a particular segment. Actually, an individual's daily choices about habitat use should be driven by energy acquisition (Fausch 1984; Railsback and Harvey 2002). Migratory individuals, however, have to strike a balance between exploitation of food resources and energy conservation for the return trip to the spawning grounds (Hendry et al. 2004). I believe the statistical relationship between segment occupancy and a segment's position relative to Arrowrock Reservoir and upstream spawning grounds is evidence of this balance.

Based on this exercise, I have developed two hypotheses that I plan to test with additional data. I believe that in watersheds having a discrete downstream migratory objective, e.g. a lake or reservoir, that bull trout distribution is strongly related to that feature. Therefore, I predict that in such a watershed I will obtain results similar to those from the Boise River basin. In watersheds without a discrete downstream migratory objective, i.e., no lake or reservoir, bull trout distribution will be strongly related to a segment's position relative to the upstream spawning grounds. As discussed above, I believe the nature of the South Fork confounded the results associated with the connectivity variable in this analysis. It appears that if the South Fork were removed from consideration, the relationship between bull trout presence and connectivity would have been positive, as I predicted.

I am going to test these hypotheses and predictions using data from the Clearwater and Lochsa drainages in north-central Idaho. The North Fork of the Clearwater River includes Dworshak Reservoir. I predict that an analysis of bull trout distribution in this drainage will yield results similar to those I obtained in the Boise River. The Lochsa drainage is unconfined and bull trout in this drainage are free to move

downstream into the Clearwater River. I predict that an analysis of bull trout distribution in this drainage will show a positive relationship between bull trout downstream position and connectivity to spawning habitat.

I am working with IDFG professionals to obtain the location data for radio-tagged bull trout in these drainages. I anticipate completing the analysis by summer 2006.

Acknowledgements

I would like to thank J. Dunham for being a creative force and my close collaborator on this project. The U. S. Bureau of Reclamation, specifically T. Salow, collected and shared the telemetry data used in this analysis. J. Benjamin provided valuable comments on an earlier version of this manuscript. This research was funded by the U. S. Fish and Wildlife Service and the U. S. Forest Service Rocky Mountain Research Station, Boise, Idaho.

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Table 1.—Sample size, fork lengths (mm), and weights (g) of 50 radio-tagged bull trout monitored in the Middle Fork (MFBR) and North Fork (NFBR) of the Boise River basin in the fall 2003.

Tag location	N	Fork length (SD)	Weight (SD)
MFBR	25	441 (60)	786 (288)
NFBR	25	489 (68)	999 (423)

Table 2.—Summary statistics for continuous variables measured in 304 stream segments in the truncated upper Boise River basin.

Variable	Average (SD)	Range	75th percentile
	Watershed (n=304)		
CONTAREA (ha)	40,686 (72,367)	258-214,041	44,729
SEGLENGTH (m)	2,731 (1,838)	85-11,368	3,792
CONNECT (km)	12.5 (13.1)	4.8-190.0	15.1
DIST (km)	41.3 (22.8)	0.0-90.2	61.5
SLOPE (%)	0.04 (0.04)	0.0-0.2	0.07
ELEV (m)	1,289 (170)	984-1,586	1,439
	Mainstem (n=74)		
CONTAREA (ha)	149,450 (71,032)	2,656-214,041	214,041
SEGLENGTH (m)	2,457 (1,744)	162-8,384	3,879
CONNECT (km)	13.0 (8.9)	4.8-53.2	15.1
DIST (km)	39.1 (20.8)	0.0 - 87.9	53.0
SLOPE (%)	0.006 (0.004)	0.000 - 0.016	0.009
ELEV (m)	1,144 (136)	984-1,539	1,235
	Tributary (n=230)		
CONTAREA (ha)	5,962 (16,382)	258-214,041	4,918
SEGLENGTH (m)	2,820 (1,862)	85-11,368	3,767
CONNECT (km)	12.4 (14.2)	4.7-189.9	15.0
DIST (km)	42.0 (23.4)	2.7-90.2	64.3
SLOPE (%)	0.06 (0.04)	0.0-0.2	0.08
ELEV (m)	1,336 (153)	1,002-1,586	1,465

Table 3.—Site-scale and landscape-scale predictor variables considered in the analysis of bull trout presence in the upper Boise River basin.

Variable (Code)	Units	Description
Site-scale variables		
Segment length (SEGLENTH)	km	Segments were delineated based on tributary junctions. A stream segment was the length of stream between two tributary junctions.
Road presence (ROAD)	P/A	Presence of a road within 100 m of a stream segment.
Fish adjacent (FISHADJ)	P/A	Presence of a occupying fish in a stream segment adjacent to a target stream segment.
Segment slope (SLOPE)	Percent	The vertical drop of a stream segment expressed as a percentage of the horizontal length of that segment.
Segment elevation (ELEV)	m	The elevation of the midpoint of a stream segment.
Landscape-scale variables		
Contributing area (CONTAREA)	ha	The portion of the basin upstream of a stream segment that drains into that segment.
Connectivity (CONNECT)	km	The weighted average of the distance from the midpoint of a stream segment to 13 occupied spawning patches in the basin.
Distance to Arrowrock (DIST)	km	The distance from the midpoint of a segment to Arrowrock Reservoir.

Table 4.—Candidate model list for logistic regression analysis of bull trout presence in the upper Boise River basin. Variable designators are explained in the text.

Model	K	Variables
Global	6	FISHADJ, SEGLENGTH, ARROWDIST, CONNECT, ROAD
1	5	FISHADJ, SEGLENGTH, ARROWDIST, CONNECT
2	5	FISHADJ, SEGLENGTH, ARROWDIST, ROAD
3	5	FISHADJ, SEGLENGTH, CONNECT, ROAD
4	4	FISHADJ, SEGLENGTH, ARROWDIST
5	4	FISHADJ, SEGLENGTH, CONNECT
6	4	FISHADJ, SEGLENGTH, ROAD

Table 5.—Results of model selection procedure for analysis of bull trout distribution. Percent concordant, specificity, and sensitivity are measures of the predictive power of a model and are expressed as percentages.

Model	K	AIC	Weight	Concordant	Specificity	Sensitivity
4	4	67.904	0.27	87.7	65.7	79.5
1	5	68.005	0.26	88.7	54.3	79.5
5	4	69.226	0.14	87.0	68.6	74.3
2	5	69.274	0.14	88.0	65.7	87.2
G	6	69.854	0.10	88.5	68.6	82.1
3	5	71.224	0.05	87.0	68.6	79.5
6	4	71.241	0.05	86.3	65.7	76.9

Table 6.—Parameter estimates and odds ratios for the composite model predicting bull trout presence in the Boise River.

Parameter	Parameter estimate (SE)	Odds ratio	95% CI for Odds Ratio
Intercept	-2.270 (1.95)		
FISHADJ	3.117 (1.40)	22.58	1.46 - 348.61
SEGLENGTH	0.845 (0.54)	2.33	0.80 - 6.75
ROAD	-0.126 (0.40)	0.88	0.40 - 1.94
CONNECT	-0.061 (0.19)	0.94	0.64 - 1.38
ARROWDIST	-0.035 (0.13)	0.97	0.75 - 1.25

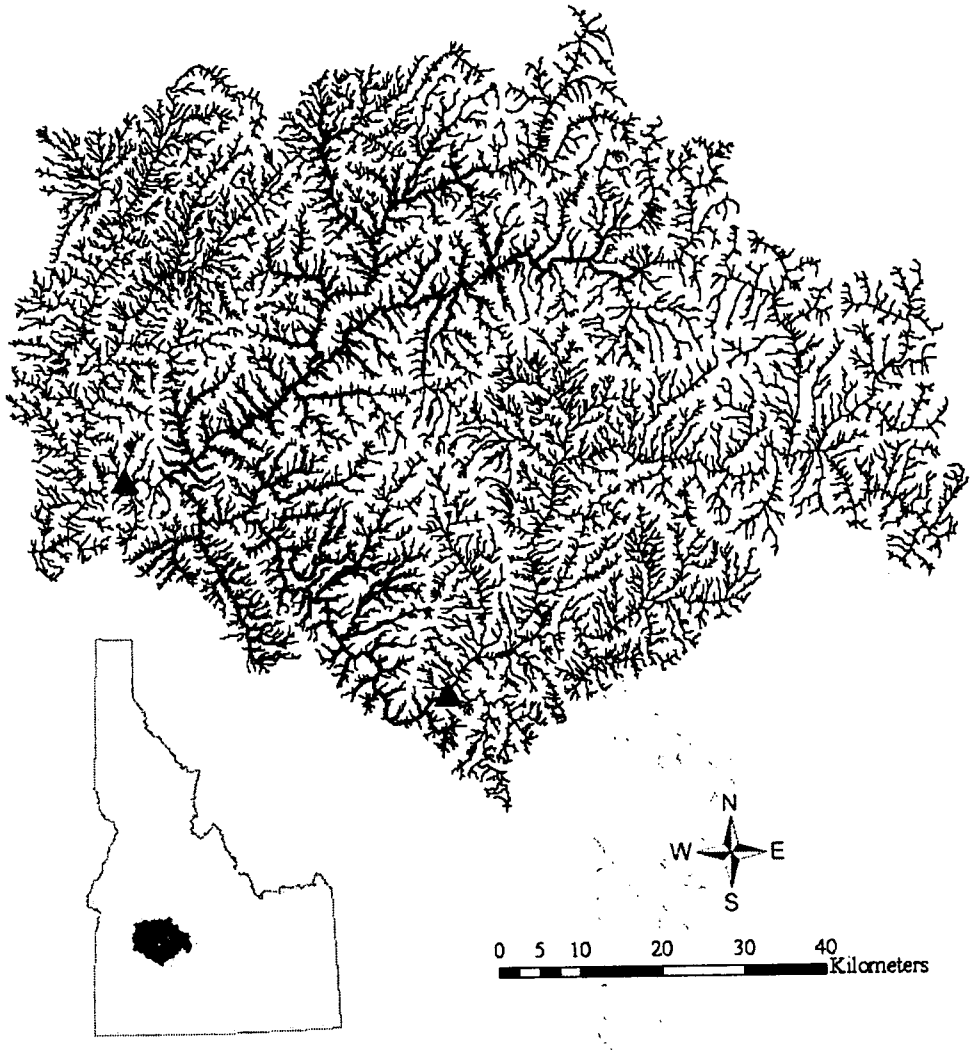

Figure 1.—The upper Boise River basin. Arrowrock Dam (left) and Anderson Ranch Dam (right) are shown with black triangles. The portion of the watershed used in this study is highlighted.

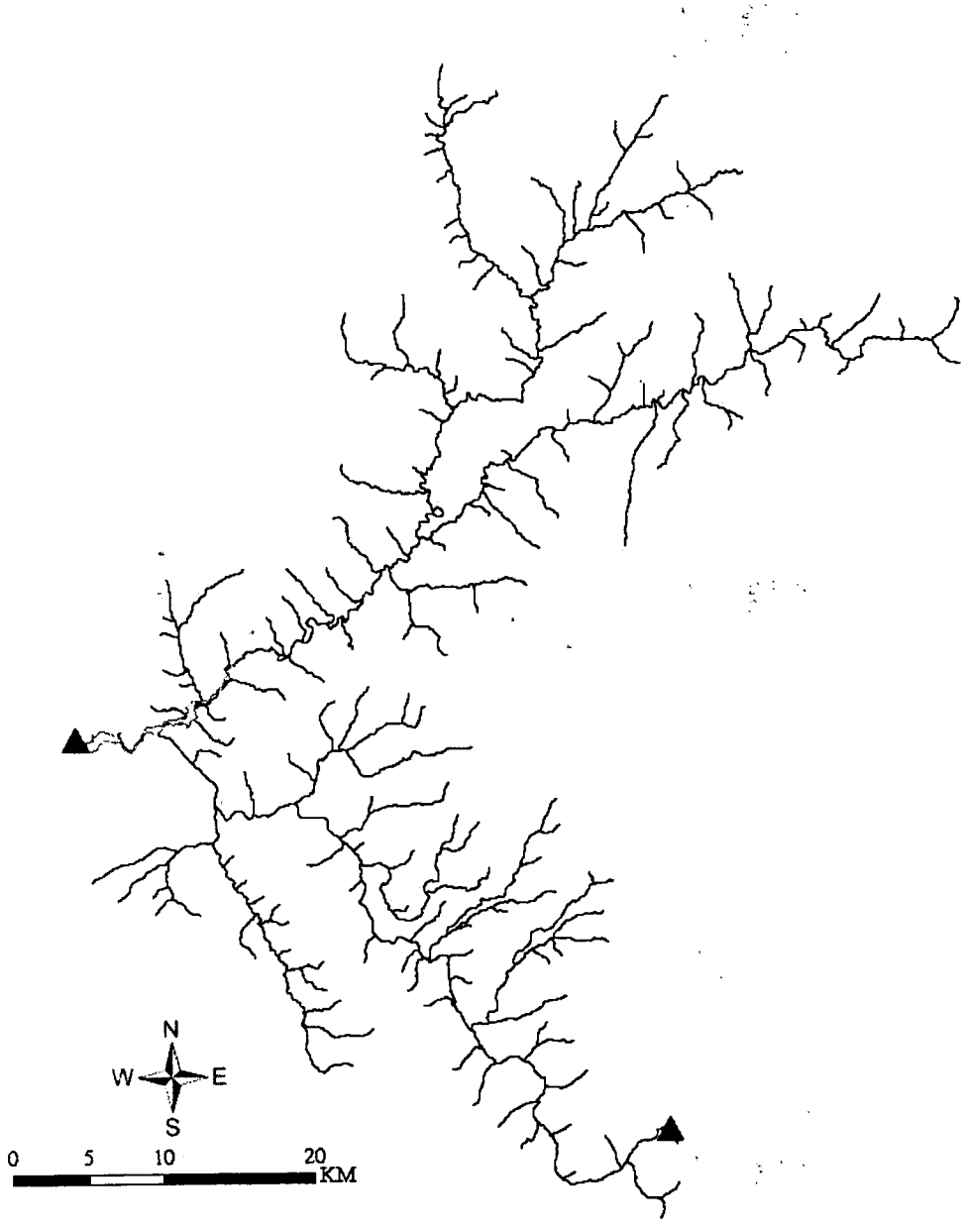

Figure 2.—The truncated watershed representing 304 stream segments. Arrowrock Dam (left) and Anderson Ranch Dam (right) are shown with black triangles.

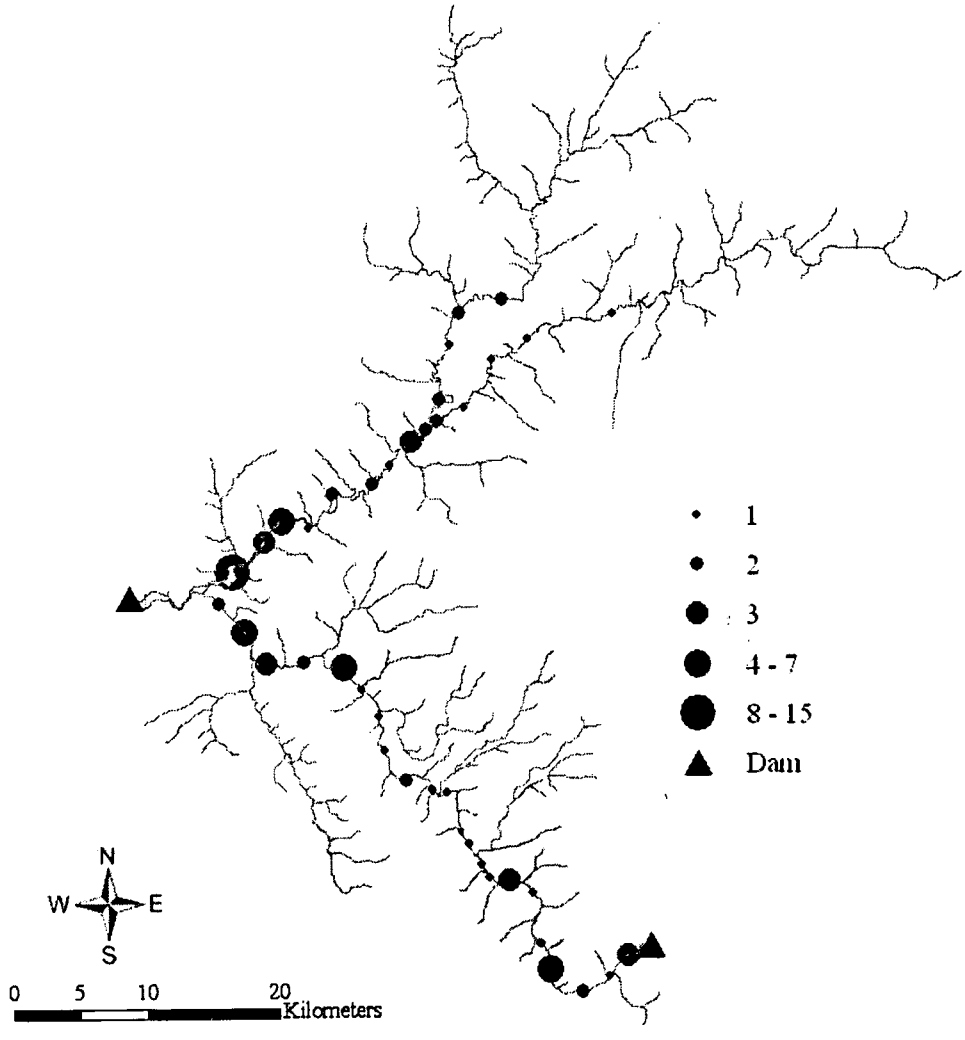

Figure 3.—Distribution of occupied stream segments. Circles represent the number of individual bull trout occupying each stream segment. .

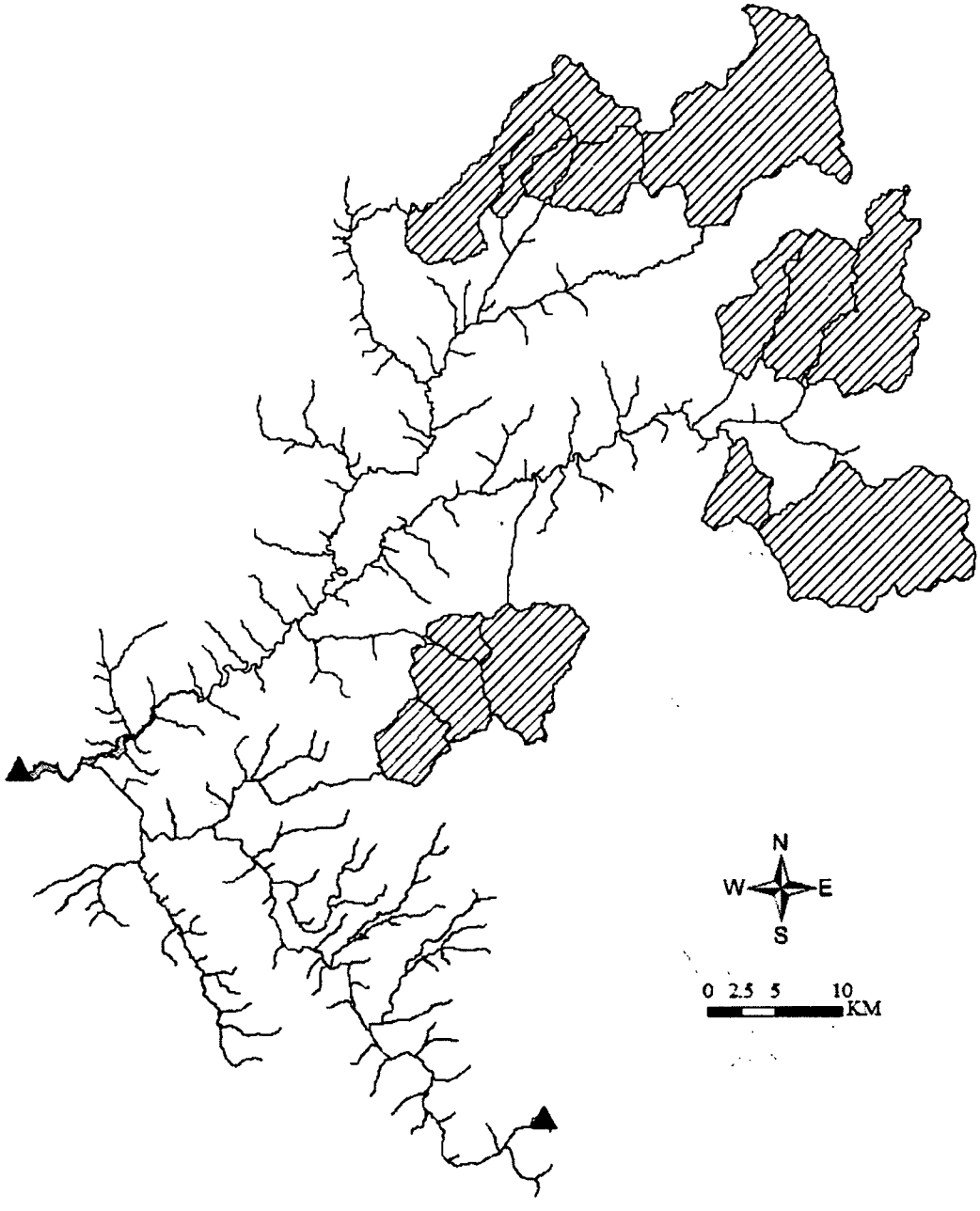

Figure 4.—Spawning patches used in the calculation of connectivity parameter.

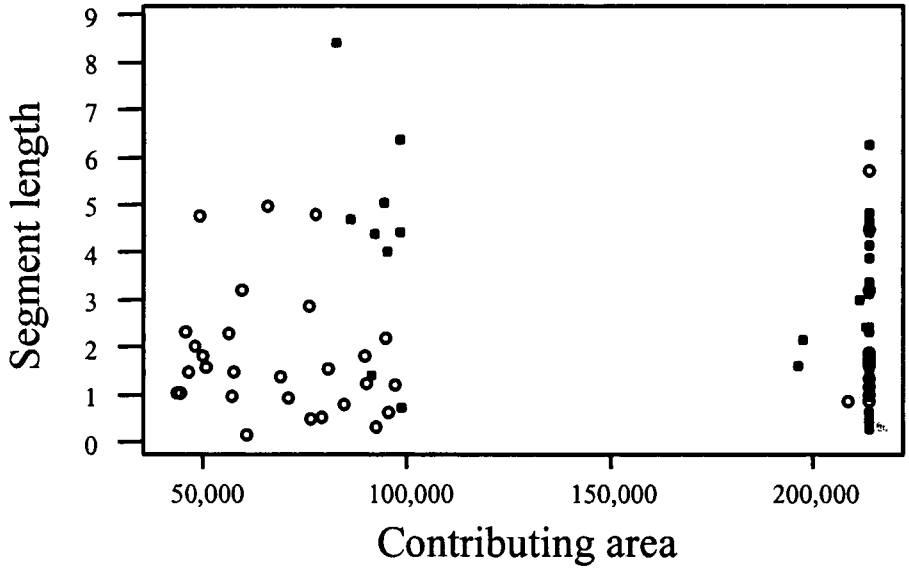

Figure 5.—The relationship between the contributing area of individual stream segments and its corresponding length. Occupied segments are denoted by closed circles.

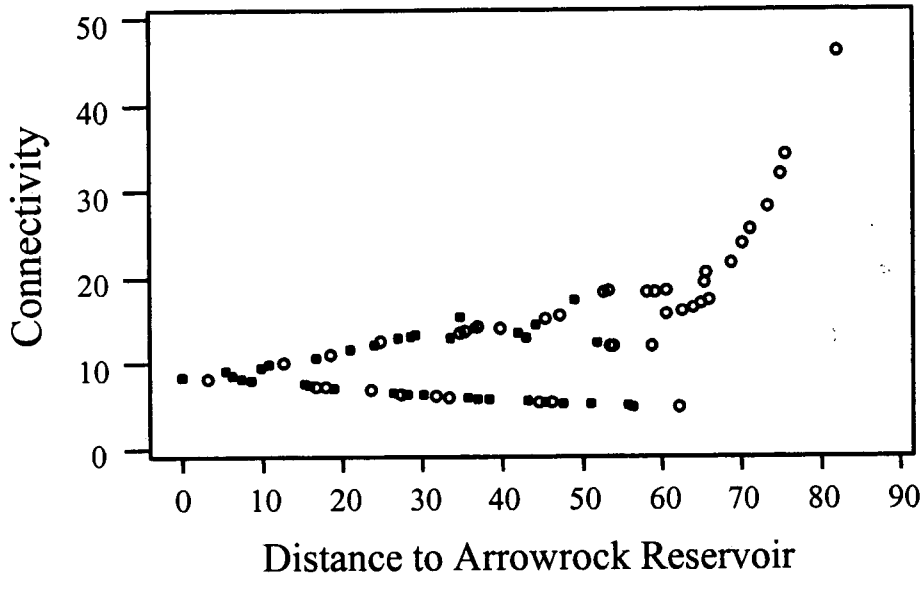

Figure 6.—The relationship between the distance of a stream segment from Arrowrock Reservoir and its corresponding connectivity value. Occupied segments are denoted by closed circles. Note the spatial relationship of the NF, MF, and SF of the Boise River is visible in this plot.